Power spectral density analysis of the standing sway of males¹

CAROLYN K. BENSEL AND E. DZENDOLET²,
UNIVERSITY OF MASSACHUSETTS

Application of power spectral density analysis to normal human standing sway showed that the power in sway was unevenly distributed among various frequencies below 1.0 Hz. Ss were divided, with regard to antero-posterior sway, into two types on the basis of the frequencies at which peaks of power occurred. The same Ss were divided into four types, with regard to lateral sway, using similar criteria. The different types appear to represent normal variations in the basic mechanism for standing upright.

The power spectral density (PSD) is the mathematical measure used to quantify a situation in which the waveform of interest cannot be analyzed into a discrete number of harmonics because the waveform is undergoing constant change (Milsum, 1966, pp. 384-385). In effect, use of the PSD measure gives the average power contained in some given frequency band of the waveform. The usual way of displaying this measure is by means of a plot of PSD against frequency. Phenomena which have been investigated by use of PSD include the EEG, finger movement, and pupil diameter (Milsum, 1966, p. 388). The results of such studies have shown that the power of the waveform is not distributed equally over frequency, as would be the case if the waveform were actually white noise, i.e., composed of frequencies at random, but is contained in peaks at certain frequencies. For example, Campbell et al (1959) have shown that the power in visual accommodation lies predominately in the region of 0.0-0.5 Hz, with a component in one or more narrow bands near 2 Hz when viewing is carried out with a large pupil.

The purpose of the current investigation was to analyze, by use of PSD, the standing sway of human Ss under two conditions. These were at the beginning of a continuous 20-min period of standing, and at the end of it.

METHOD

Subjects

These were 10 male undergraduates at the University, who were enrolled in an introductory course in psychology. They received credit toward fulfillment of a course requirement in return for their participation. They were selected from a larger group of volunteers, so that the 10 had no history of a head injury, of muscle or bone injury to the legs or feet, of fainting spells, or of a recent illness. In addition, none of the Ss were taking any medication with the possible exception of multipurpose vitamin supplements.

Apparatus

The sway transducer on which S stood was a square wooden platform, approximately 68 cm along each side and 2 cm thick. The platform was supported at the center of each side by the ends of four horizontally-positioned steel bars of rectangular cross section which extended under the platform. The platform was also firmly fastened to these bars by a machine screw through each bar. The other ends of the supporting bars were rigidly fastened to a framework of welded steel positioned below the platform, and which was approximately the same dimensions as the platform. Strain gauges were placed on all four bars, and only those on opposing bars were connected as elements of two separate Wheatstone bridge circuits. This arrangement allowed simultaneous and separate recording of antero-posterior and lateral sways when the S was positioned properly.

The outputs of the separate bridge circuits were recorded by means of a two-channel polygraph (Grass Instrument Company, Model 5, with 5P1 preamplifiers). The preamplifier sensitivities were set at 0.05 mv/cm for all Ss. The sensitivity of the platform itself was such that a 2.0-kg mass placed 25 cm from the center of

the platform, along a line between the supporting bars, produced a 1.0-cm deflection of the record, with the preamplifier sensitivity set at 0.02 mv/cm.

Procedure

The S was shown the platform, asked to remove his shoes, and then blindfolded. Instructions were read to him in which he was asked to clasp his hands loosely in front of him and to stand quietly in a relaxed manner without moving his feet, and to keep his weight distributed equally on both feet. S then had earphones placed on his head, and white noise at 70 dB SPL was delivered through them. He was assisted in positioning himself on the platform, with his heels together and his feet spread at about 45 deg to one another. The recordings began immediately, and S remained in this position for 21 min. Only the sway during the period from 0 to 1 min, designated Time 0, and from 20 to 21 min, designated Time 20, was recorded and examined in this experiment.

Scoring

The polygraph records were scored every 0.2 sec with the aid of an "Oscar K" (Benson-Lehner Corporation), in terms of mm of positive or negative deflections from an arbitrary baseline. This procedure gave 300 data points for the 1 min period. Antero-posterior and lateral sways were considered separately. The statistical analyses were carried out on a CDC 3600 digital computer (Control Data Corporation), with an autocorrelation function being computed first. The PSD function was obtained via the computer as a Fourier transform of the autocorrelation function. The value of the time lag used in the computation of the autocorrelation function was increased from 0 sec in steps of 0.2 sec, and the value of the longest lag was 20 sec. This highest frequency for which PSD values could be accurately computed was 2.5 Hz, as calculated from the Nyquist Sampling Theorem. The number of PSD points obtained was 100 with the value of the frequency increment between points being 0.025 Hz. However, values of PSD below 1.0 were not utilized in plots of PSD vs frequency.

RESULTS

Antero-posterior sway

Plots of PSD vs frequency for sway in this direction during Time 0 and Time 20 were made for each S. The highest PSD values lay between 0.0 and 0.4 Hz in both of these periods. On the basis of visual inspection, there appeared to be two groups of Ss. One group consisted of six Ss, and was selected because their PSD plots showed a dip at about 0.125 Hz, and a peak between 0.150 and 0.175 Hz. A similar dip and peak were also apparent at 0.225 and 0.250 Hz, respectively. Values of PSD above and below these approximate frequencies were more variable, and, therefore, of lesser value in characterizing the Ss. A log-log plot of the arithmetic mean of the PSD's of these Ss is given in Fig. 1. A curve of this form will be termed Type A_A, where the subscript stands for the antero-posterior direction of sway. The mean curve clearly shows the criteria dips and peaks at the frequencies indicated.

A mean plot of the PSD's of the same six Ss after 20 min of standing is also given in Fig. 1. It can be easily seen that the main change with time was an increase in total power, i.e., the Ss swayed more, and that the various dips and peaks which occurred earlier are no longer visible.

A second group consisted of three Ss, and their PSD plots were characterized by a dip at 0.150 and a peak at 0.250 Hz. A mean PSD plot of these Ss is given in Fig. 2, with the label of Time 0.

Fig. 1. Mean power spectral density (PSD) vs frequency curves for antero-posterior standing sway of six males. The Time 0 and Time 20 curves are for sway of the same Ss, each for a period of 1 min, immediately upon getting into position on the apparatus, and after having stood in position continuously for 20 min, respectively. Curves at Time 0 of individual Ss in this group showed dips at about 0.125 and 0.225 Hz, and peaks at about 0.170 and 0.250 Hz. This form of curve is designated Type A_A , the subscript indicating the antero-posterior direction. The curve of Time 20 shows a clear increase in the amount of sway, and a suppression of the earlier peaks.

Fig. 2. Mean PSD vs frequency curves for antero-posterior standing sway of three males. Time 0 and Time 20 have the same meaning as in Fig. 1. Each of these Ss showed a dip at 0.150 Hz and a peak at 0.250 Hz in the Time 0 curve. This form of curve is designated Type B_A . These Ss showed an apparent shift of the 0.250 Hz peak at Time 0 to a position at about 0.15 Hz at Time 20. This is in contrast to Type A_A (Fig. 1) in which the early-appearing peaks were suppressed at Time 20.

The criteria are clearly evident, and the curve is termed Type B_A . As before, a mean plot of the same Ss after 20 min, Time 20, is also given in the same figure. The main change with time is again an increase in the amount of sway, much greater than in Fig. 1, i.e., Type A_A . The primary dips and peaks are still evident, although somewhat reduced, but have, in addition, apparently shifted to slightly lower frequencies.

The curve for the remaining S will not be described here, except that it showed a very broad peak at 0.150 Hz. It clearly did not belong to either of the other two types considered, but it was not at all clear, with only one S, if it were representative of a class of curves.

Lateral sway

The PSD values obtained from the analysis of lateral sway were generally lower than those for antero-posterior sway, but, again, most of the power lay between 0.0 and 0.4 Hz. As with antero-posterior sway, Ss were grouped according to characteristic dips and peaks in their individual PSD plots at Time 0. The patterns exhibited were not the same, however, as those for antero-posterior sway. The first group consisted of three Ss who showed a broad peak at about 0.100, a dip at 0.150, and a double

Fig. 3. Mean PSD vs frequency curves for lateral sway of three males. Individual curves at Time 0 showed a broad peak at about 0.10, a dip at 0.15, and a double peak between 0.20 and 0.30 Hz. This form is designated Type A_L , with the subscript denoting the direction of sway. A marked reduction in the size of the peaks occurred at Time 20, similar to what happened with the Type A_A curve (Fig. 1). This is the only group in which the amount of sway was not markedly greater overall at Time 20 than at Time 0.

peak between about 0.200 and 0.300 Hz. This curve is designated Type A_L , with the subscript indicating lateral sway, and the mean PSD plot is shown in Fig. 3. The double peaks are clearly evident in the mean curve. The curve for these Ss at Time 20 is also given in Fig. 3. It shows an increase in power, i.e., amount of sway, mainly in the frequency range below 0.200 Hz. In addition, there is a marked reduction in the amplitude of all the peaks present at Time 0, especially of the double peaks.

The second group also contained three Ss. These showed a slight peak at 0.100, a dip at 0.150, and a single peak at 0.200 Hz. This curve is designated as a separate type, Type B_L , because of the single peak at 0.200 Hz, as opposed to Type A_L with its double peaks at this frequency. Otherwise, the two types appeared similar at Time 0. The curve is shown in Fig. 4, along with the curve for the same Ss at Time 20. The latter curve shows an overall increase in power, and an apparent shift of the dips and peaks to frequencies of slightly lower values.

The third group consisted of two Ss who showed a broad peak at 0.150, a dip at about 0.225, and a small peak at 0.300 Hz. This form of curve is designated Type C_L . The mean curve is displayed in Fig. 5, along with the mean curve for these Ss at Time 20. The latter curve shows the usual overall increase in power, but the

Fig. 4. Mean PSD vs frequency curves for lateral sway of three males. The Time 0 curve is designated Type B_L and characterized by a slight peak at 0.10, a dip at 0.15, and a single peak at 0.20 Hz as opposed to a double peak with Type A_L (Fig. 3). The curve at Time 20 shows a shift of peaks toward lower frequencies, as with the Type B_A curve (Fig. 2).

characteristic dips and peaks remain relatively unchanged, i.e., they are neither reduced in amplitude, nor shifted in frequency.

The final group of Ss, two in number, showed only slight dips and peaks. The dips occurred at 0.125 and 0.175 Hz. The peaks occurred at 0.150 and in the vicinity of 0.250 Hz. This form is designated Type D_L. The mean curve of these Ss is shown in Fig. 6, with a curve for the same Ss at Time 20. The earlier mean curve shows the slight dips and peaks used to characterize the individual Ss. The later curve shows the typical overall increase in amount of sway. In addition, it shows a large peak at 0.225 Hz which seems to be based on the slight peaks at 0.150 and 0.250 Hz, and the abolition of the slight dip at 0.175 Hz with its subsequent inclusion in the peak.

DISCUSSION

Although the separation of only 10 Ss into a number of groups based on a visual inspection of the PSD curves may appear to be premature, the validity of such a procedure is based on the uniqueness of the criteria, and the fact that a similar procedure had been used successfully in the categorization of the forms of plots of absolute thresholds of males for standing sway in response

Fig. 5. Mean PSD vs frequency curves for lateral sway of two Ss. The Time 0 curve is designated Type C_L, with the individual curves showing a broad peak at 0.150, a dip at about 0.225, and a small peak at about 0.30 Hz. The curve at Time 20 shows the dips and peaks unchanged as to frequency.

to various low-frequency sinusoidal electrical stimuli. These stimuli were applied by means of electrodes placed on the Ss' mastoid processes (Dzendolet, 1964). The result of that classification was the separation of the 32 Ss into four major types which included 87.5% of the Ss, and two minor types. The validity of the visual classification was supported, at least for the major types, by the results of a factor analytic technique applied to the data.

The general results of the current investigation were similar to those in which other receptor-effector systems had been analyzed in terms of PSD. The power in standing sway was distributed unevenly among a number of frequency bands below 1.00 Hz, with most of the power lying between 0.0 and 0.4 Hz, regardless of sway direction. Therefore, it appears that there is a range of frequencies within which body sway normally lies. As mentioned earlier, the power-containing peaks of primary interest lay between about 0.100 and 0.300 Hz.

In antero-posterior and lateral sways during Time 0 for all the various types are compared, it is clear that there was generally a

Fig. 6. Mean PSD vs frequency curves for lateral sway of two Ss. Individual curves showed only slight dips at 0.125 and 0.175 Hz, and slight peaks at 0.150 and 0.250 Hz. This form of curve is designated Type D_L. The Time 20 curve shows a large peak at 0.225 Hz, which seems to be a summation and increase in the earlier, slighter peaks. The increase in power at Time 20 is as great as in antero-posterior sway, i.e., in Figs. 1 and 2.

greater amount of sway in the antero-posterior direction. Within this direction, there was more power in the Type A_A curve than in the Type B_A. An exception to the above generality concerning antero-posterior and lateral sways occurred with the Type D_L curve which showed a greater amount of power than was in the Type B_A curve. The general finding, however, is in agreement with the works of Fearing (1924) and of Edwards (1942). It is also clear that the amount of sway increased with the time of standing, as shown by the increase in PSD for both the antero-posterior and lateral directions, with the exception of the Type A_L curve. This showed an increase in sway below 0.200 Hz, but essentially none above this frequency.

There appeared to be no relation between the antero-posterior and lateral sway types other than their change in sway patterns with time. The Ss belonging to the various lateral types were not the same as those in the similarly labelled antero-posterior types with one possible exception. All three Ss of Type B_L were among the six Ss making up Type A_A.

If the mean PSD curves for the Ss making up the various types

of lateral sway at Time 20 are examined, it will be seen that they also fall into certain patterns with respect to the curves at Time 0. Type A_L shows an overall relative decrease in the size of the peaks which occurred earlier. Type B_L shows a shift in the peaks to lower frequencies. Type C_L shows no change at all, except for the overall increase in power mentioned earlier. Type D_L shows a relative increase in the size of the peaks. Types A_A and B_A, i.e., the curves for antero-posterior sway, are similar to Types A_L and B_L, respectively. The only type which seems to be missing from these possibilities, is a type in which the peaks are shifted to higher, rather than to lower frequencies.

The occurrence of these patterns, i.e., changes in the peaks with increase in time of standing, would appear to suggest that the initial separation into types was a meaningful one. The various types can then be taken to be variations of the basic mechanisms which are employed in the normal process of standing.

REFERENCES

CAMPBELL, F. W., ROBSON, J. G., & WESTHEIMER, G. Fluctuations of

accommodation under steady viewing conditions. *J. Physiol.*, 1959, 145, 579-594.

DUNSTONE, J. J., & DZENDOLET, E. Types of objective electrical vestibulograms. *Percept. mot. Skills*, 1964, 19, 899-904.

EDWARDS, A. S. The measurement of static ataxia. *Amer. J. Psychol.*, 1942, 55, 171-188.

FEARING, F. S. The factors influencing static equilibrium. I., *J. comp. Psychol.*, 1924, 4, 91-121.

MILSUM, J. H. *Biological control system analysis*. New York: McGraw-Hill, 1966.

NOTES

1. This work was supported in part by Public Health Service Research Grant NB 03675-05 from the National Institute of Neurological Diseases and Blindness.

2. Address: Department of Psychology, University of Massachusetts, Amherst, Mass. 01002

(Accepted for publication July 9, 1968.)